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THE TERTIARY HISTORY OF THE TENNESSEE RIVER

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SUMMARY AND CONCLUSIONS.

The following paper was presented as a thesis in a graduate course in physiography at Harvard University in June, 1904, on the basis of a study of previous essays concerning the Tennessee River, a review of the general problem of river-capture, and an examination of the district about Chattanooga during a two-weeks' excursion in April, 1904. The writer is under obligations to Dr. C. Willard Hayes, Mr. Marius R. Campbell, and others, for numerous courtesies extended in connection with both field and office work.

INTRODUCTION

The Tennessee River, after flowing southward through a broadly open, longitudinal valley for some distance in the eastern part of the state of Tennessee, to a point near the city of Chattanooga, turns abruptly westward through a deep, narrow, winding gorge, which is cut in the high, flat-topped mountain known as Walden Ridge; and then bends southward again in a longitudinal valley similar to the one it occupied before entering the gorge. Both of the longitudinal valleys are opened on anticlines of easily eroded limestone, while the transverse gorge cuts across a shallow syncline of resistant sandstone underlain by limestone. The turn of the river from the broad longitudinal valley abruptly westward through a high mountain barrier presents a problem that has interested physiographers for some time.

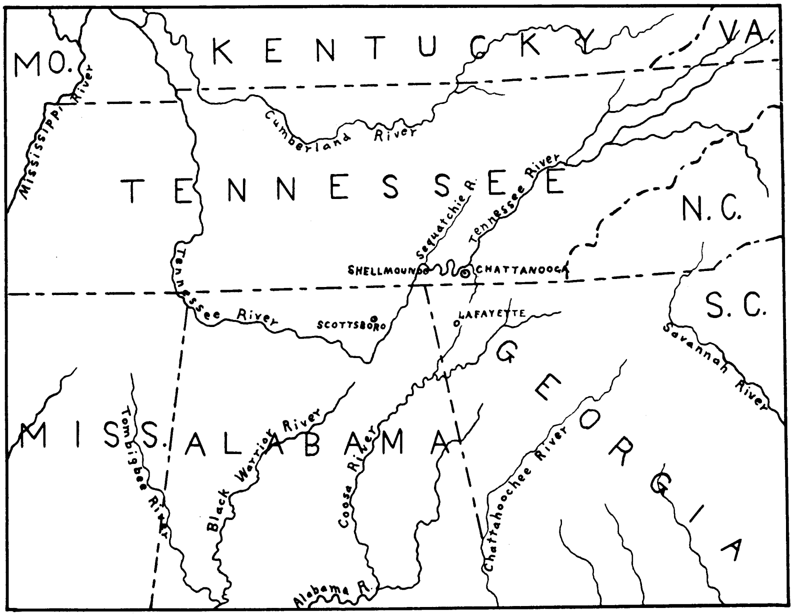

FIG. 1.—Location map.

Two hypotheses have been advanced in explanation of this problem. According to one, the river acquired this course across the mountain some time before the close of the Cretaceous period of baseleveling, probably near the close of that period, when the present flat top of the mountain was continuous with the rest of the Cretaceous peneplain; after later uplift the river continued to flow in that course throughout the Tertiary and Recent cycles, cutting its narrow transverse gorge below the level of the Cretaceous peneplain at the same time that the broad longitudinal valleys in softer rock were being excavated. According to the other hypothesis, throughout the Tertiary cycle the river flowed on southward in the longitudinal valley east of the mountain, and so, by way of the Coosa and Alabama Rivers, into the Gulf of Mexico, continuing in this course until the present broad valleys both north and south from Chattanooga were completed (Fig. 2); then, at the close of the Tertiary cycle, by a process of stream capture, the Tennessee was tapped at a point near Chattanooga by a branch of a stream occupying the valley west of the mountain, and so diverted from the former course to its present course through the gorge (Fig. 3). In recent years this latter theory has been most strongly supported. Certain new evidence, now available, appears to afford good reasons for adopting the first of these theories. It seems desirable, therefore, to review the previous considerations of this problem, weighing carefully the evidence both for and against each theory.

LITERATURE

In 1894 there appeared a paper by C. Willard Hayes and Marius R. Campbell on *The Geomorphology of the Southern Appalachians.* Their essay gives a somewhat detailed account of the physiographic history of the region treated, and devotes a number of pages to the Tennessee drainage problem. The results of their studies led them to believe in the post-Tertiary diversion of the Tennessee from a former southward course; hence they support the second of the above hypotheses with a variety of evidence. This evidence is discussed in detail below.

In a later paper, on *The Physiography of the Chattanooga District,* Dr. C. Willard Hayes discusses the physiographic development of the region more fully than in the former paper by himself and Mr. Campbell. Dr. Hayes traces the past history of stream-adjustments throughout the region in great detail, offering a new interpretation regarding one or two points in the Tennessee problem, but supporting the main conclusion reached in the earlier report.

In 1900 Mr. Charles T. Simpson published a paper on *The Evidence of the Unionidæ Regarding the Former Courses of the Tennessee and Other Southern Rivers.* Working along entirely different lines, Mr. Simpson independently came to the same conclusion as that reached by Messrs. Hayes and Campbell, supporting the second of the two hypotheses already referred to, on biological evidence alone. This came as a most striking confirmation of the work of Hayes and Campbell, and the paper created much interest. The biological evidence is given in greater detail in Mr. Simpson's monograph on *The Naiades, or Pearly Fresh-Water Mussels.* The nature of this argument is considered below.

In 1901 Mr. Charles C. Adams accepted the theory of capture as set forth by Messrs. Hayes and Campbell, explaining upon the basis of this theory certain faunal peculiarities of the region in question. Mr. Adams' paper, entitled *Baseleveling and its Faunal Significance, with Illustrations from the Southeastern United States,* accounts for the differences existing in members of the same group of shells as found in the Tennessee and Alabama systems as being due to a separation of the group into parts by the diversion of the upper Tennessee at Chattanooga, and subsequent evolution of these two groups along somewhat different lines.

A recent number of the *Journal of Geology* contains an article by Mr. C. H. White on "The Appalachian River *versus* a Tertiary Trans-Appalachian River in Eastern Tennessee." Mr. White reviews the evidence presented by Hayes and Campbell, believes that it is not sufficient to prove the diversion of the Tennessee from a former southward course, and concludes in favor of the first of the hypotheses given above—that the river has occupied its present course across the mountain since the Cretaceous cycle. The biological evidence furnished by the Unionidæ is not considered by Mr. White, nor does he present direct evidence in support of his conclusions.

Professors T. C. Chamberlin and R. D. Salisbury, in their recent textbook on *Geology* (Vol. I, pp. 164-68), devote several pages to a presentation of the Tennessee problem as an example of river capture due in part to crustal warping.

THE PROBLEM STATED

Hayes and Campbell have shown that near the close of the Cretaceous period the region about Chattanooga had been reduced to a nearly featureless peneplain over which the streams wandered with sluggish courses. The completion of this peneplain marked the close of the first physiographic cycle of which we have satisfactory evidence in the district. With the elevation of the region above sea-level at the beginning of the Tertiary, the second cycle commenced, during which the streams, flowing over weak rocks, were able to excavate broad valleys nearly to their headwaters, developing in these valleys a second plain of denudation, the Tertiary peneplain, while hard rock regions remained unreduced, preserving the Cretaceous peneplain over broad areas. This Tertiary cycle was followed by depressions and elevations, the final result of which has been to leave the Tertiary peneplain well elevated and to allow the streams to cut their valleys some distance below its level. The elevations and depressions were accompanied by distinct warping, and the warping is correlated with certain drainage modifications (1894).

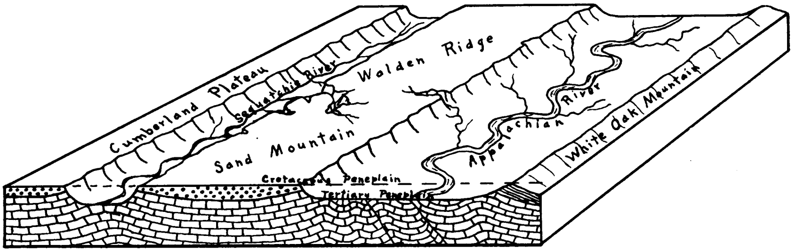

FIG. 2.—Supposed former course of Tennessee (as Appalachian).

Dr. Hayes, in his report on the physiography of the Chattanooga district, gives specific names to the different peneplains, the Cretaceous peneplain being known as the Cumberland, the Tertiary as the Highland Rim, and a still later level, near the present beds of the streams, as the Coosa peneplain. We are not here concerned with the more exact ages ascribed to the several peneplains, nor with the last formed of the three, the Coosa. And since we are dealing with a particular problem, which is more fully discussed in the earlier paper by Hayes and Campbell, we will, for sake of convenience, employ the more general terms used in that essay.

In the accompanying figures (Figs. 2 and 3) the flat top of Walden Ridge, continued southward as Sand Mountain, represents a remnant of the old Cretaceous peneplain. In the broad valleys on either side of this mountain was developed the Tertiary peneplain, remnants of which are still distinctly visible in places, although post-Tertiary erosion has destroyed much of its surface. Fig. 2 shows the supposed former course of the Tennessee as given by those who support the theory of capture. According to this theory, a great river, called the Appalachian by Hayes and Campbell, flowed southward past Chattanooga, across what is now the low divide near Lafayette, on south through this valley to the Coosa River, and thence by way of the Alabama River to the Gulf. In the Sequatchie valley, west of Walden Ridge, a parallel, southward-flowing, subsequent stream, the Sequatchie River, is believed to have occupied a level 100 feet lower than its neighbor to the east, thus having some advantage over the latter. It is conceived that near the close of the Tertiary period a branch of the Sequatchie worked headward through the ridge, finally tapping the Appalachian River at a point near the present site of Chattanooga, and diverted its waters westward down through the gorge to the lower level of the Sequatchie valley, thus giving birth to the present Tennessee River. The broad valley southward from Chattanooga, being thus deserted by the upper Appalachian River, was left to the occupancy of the shrunken lower portion of that beheaded stream, and a small tributary of the new Tennessee River (Chicamauga Creek and its branches) succeeded in pushing the low divide which was first established at the point of capture southward along this valley nearly to Lafayette.

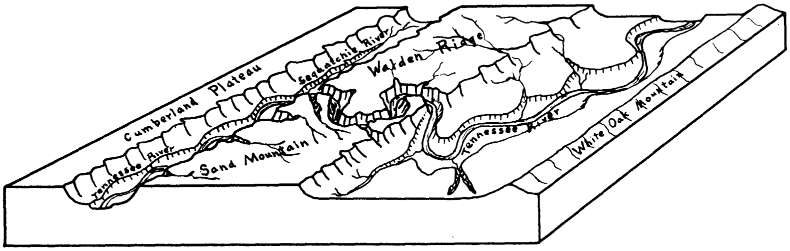

FIG. 3.—Present course of Tennessee River.

Opposed to this theory, which has as its essential feature a grand example of river-capture, is the conception that since the close of the Cretaceous period, at least, the drainage relations in this region have been essentially as they now are; that the present valleys were carved by the streams which now occupy them; and that, so far as the time element is concerned, all of these valleys are of practically the same age, no recent capture having taken place.

Previously to the appearance of Mr. White's paper, above referred to, and before I was aware that he was interested in the Tennessee problem, I became convinced that the evidence presented by Messrs. Hayes and Campbell, and by Mr. Simpson, while very suggestive, was not conclusive. Being at the time interested in the study of river-capture in general, I was in hopes that an examination of the Chattanooga district with this particular drainage problem in mind might result in securing certain evidence which would throw additional light on the question. Accordingly, in April, 1904, the region was visited, and a brief study made of the winding gorge; the river above and below the point of supposed capture; the divide between the Tennessee and Coosa drainage south of Chattanooga, and the small streams flowing north and south from this divide; the Sequatchie River in the valley west of the mountain, a branch of which is supposed to have effected the capture; and the valley southwest of Scottsboro, Ala., which has been contrasted with the gorge of the Tennessee. Certain facts were noted which seemed to indicate that the Tennessee River has occupied its present course since the Cretaceous period of baseleveling, instead of having been diverted westward by a comparatively recent capture; and which seemed to explain satisfactorily the peculiar features of the gorge on the basis of this hypothesis. Since this evidence would lead to a conclusion so radically different from that reached by former students of the problem, it is desirable carefully to consider both lines of evidence—that in favor of the theory of capture, as well as that in favor of the alternative theory.

EVIDENCE IN FAVOR OF THE THEORY OF CAPTURE

Hayes and Campbell base their conclusions, that the southward-flowing Appalachian River was captured near the site of Chattanooga by a branch of the Sequatchie River, upon the three following lines of evidence: (1) the character of the divide between the Tennessee and Coosa-Alabama drainage basins; (2) a comparison of the amount of material eroded from the Appalachian valley with that of the sediment deposited at the mouth of the Coosa-Alabama River; (3) the character of the gorge of the Tennessee below Chattanooga.

Evidence from the Coosa-Tennessee divide.—Regarding the character of the divide between the Tennessee and Coosa-Alabama basins, Hayes and Campbell point out the fact that the divide is low and indistinct, and that it occurs as a less prominent feature in the well-defined, broad, open valley which is continuous to the northeast with the valley of the present Tennessee above Chattanooga, and to the southwest with the valley of the present Coosa and Alabama Rivers. The well-marked character of this broad valley, which continues directly across the dividing line between the two river basins, is thought to indicate the former presence of a large northeast-southwest stream, the Appalachian River. This being true, the present position of the large stream must have resulted from river-capture, and a diverting stream must have led the upper Appalachian westward through the new-made gorge.

It does not seem to me that the baseleveled character of the divide alone necessitates the conclusion that a large stream once flowed across it. In order to make such a conclusion necessary, we should have to assume that every such broad valley developed across a low divide must have been carved by a large stream—an assumption which does not seem to be warranted. The region is one of parallel bands of alternating hard and soft rocks. (This parallelism of structure would prevent the development of dendritic drainage, the absence of which is noted by Hayes and Campbell.) The soft bands are rapidly eroded, while the hard bands remain as intervening ridges. Thus the region is characterized by broad, northeast-southwest valleys, many of which are occupied by very insignificant streams between whose headwaters are inconspicuous divides. Nor does there seem to be any need of assuming the former presence of larger streams, since the softness of the rocks and their easy solubility sufficiently account for the phenomena observed. Indeed, there are cases in which it seems practically certain that no drainage readjustments have taken place in recent geological time. Hayes and Campbell recognized this fact, and, after stating the argument and their conclusion, added another paragraph in which they said that, while they formerly regarded the argument as conclusive, further study of other similar divides had led them to modify this opinion. They cited the divides between the Potomac and James, and between the James and Roanoke basins, as cases similar to the one in question, but where there was no reason, so far as known, for supposing that a large stream ever existed. Evidently, then, this one of the arguments is only of negative value; it is permissive, but in no wise conclusive. That in this particular case the divide really presents features which make it difficult to conceive how a large stream could ever have flowed across it, is pointed out in subsequent pages.

Evidence from the volume of material eroded and deposited.—The second line of evidence developed by Hayes and Campbell is as follows: If we can ascertain the quantity of sediments carried out by the Alabama River system during Tertiary times, and can also ascertain the quantity of material eroded from the basins of the Coosa-Alabama system and the upper Tennessee system during Tertiary times, we can then compare the two results and find out whether the amount of sediments deposited is balanced by the amount of material eroded from the Coosa-Alabama basin alone, or whether it is only balanced when we add to it the material eroded from the upper Tennessee basin also. Lines are drawn midway between the Alabama and the Chattahoochee on the east, and between the Alabama and Tombigbee on the west, and all the Tertiary sediments between the two lines regarded as the material carried out by the Alabama system in Tertiary times. The amount is estimated at 2,340 cubic miles. Turning now to the amount of material eroded from the basin of the present Alabama system during Tertiary times, a careful estimate places the amount at 622 cubic miles. It is evident from these figures that some other area must have contributed to the formation of the vast amount of sediments laid down opposite the old mouth of the Alabama. If we add to the material eroded from the basin of the present Alabama system the material eroded from the basin of the upper Tennessee system, it is found that the total material eroded from both basins, during Tertiary times, is about 2,500 cubic miles. This agrees closely enough with the 2,340 cubic miles of Tertiary sediments found opposite the old mouth of the Alabama River. It follows from this that the Upper Tennessee basin must formerly have drained out through the Coosa-Alabama system by a river occupying the old valley across the divide south of Chattanooga, that stream having since been diverted westward through Walden Ridge by a branch of the Sequatchie River.

If all of the sediment laid down in the sea opposite a given river is brought there by that river alone, then this evidence would indeed seem conclusive in favor of the theory of capture. It is believed, however, that such an assumption would be contrary to what we know regarding the behavior of river-brought sediment under marine control. It would imply an absence of all appreciable transportation and distribution under the action of oceanic and littoral currents, the well-recognized drift to leeward produced by storm-waves, and the small but long-continued action of the tides. That these agencies have a very important influence seems well established by a large number of concrete observations. According to LeConte, the sediment brought down by the Amazon is carried seaward by a strong tide, taken up by the ocean currents, swept to a distance of 300 miles or more, and much of it deposited on the coast of Guiana (p. 40). It is estimated that the Nile carries out past its delta 36,600,000 cubic meters of silt every year. Yet this enormous amount of sediment apparently does not add to the seaward extent of the delta, because of a powerful marine current that sweeps past the coast and transports the sediment far eastward, where it is finally thrown down along the coast of El Arich desert. Over a portion of Blake plateau, southeast of Georgia, between depths of 100 and 600 fathoms, the bottom seems to be swept clean of mud, ooze, and almost so of living species. Agassiz attributed this to current action. And, again, LeConte tells us that the sediments brought into the Gulf of Mexico by the Gulf rivers are swept along by current action, and in part deposited on Florida Point, and the Bahama Banks (p. 40), while Mr. White (p. 36) refers to the fact that "after the formation of the Nita Crevasse in 1890, fine mud from the Mississippi was deposited in Mississippi Sound even up to the mouth of Mobile Bay, driving out the fish and killing the oysters" (E. A. Smith *et al.*, p. 30). Account must also be taken of the numerous well-recognized cases of transportation due to the set or drift given by storm-made waves and currents. Dana records the drifting of large quantities of coal and brick from wrecked vessels many miles from where they were dropped (p. 224). An anchor with ten fathoms of chain attached was carried one and a half miles in three weeks (p. 225). The effect of such storm-made waves and currents on small gravel, sand, and the finer sediments must be profound. Coarse gravel on Moray Firth is drifted eastward for over fifteen miles (Geikie, p. 418); the groundswell off Land's End washes cobbles weighing as much as one pound into lobster pots at a depth of thirty fathoms (Douglas, quoted by Geikie, p. 419). Much of the material forming the great barrier beaches along the Atlantic coast is believed to have been brought from considerable distances. As a result of the strong southward drift along the coast of the southeastern United States, according to Professor Bache, the siliceous sands are carried the whole length of the limestone coast of Florida (LeConte, p. 36). Dana tells us that the large amount of sediments brought to the sea by all of the rivers of the Atlantic coast is *widely* distributed (p. 224). It is believed, then, that however closely the estimates of material eroded from a river basin and of material found opposite the mouth of that river agree, or how widely they may disagree, no conclusions as to the former extent of those river basins can be rightly based on such estimates, in the face of the strong probability, amounting almost to a certainty, that an unknown amount of sediments carried out to sea by that river have been transported by marine action beyond the area in front of the river, while an unknown amount of sediments brought out by other rivers has been carried into that area.

There are still other considerations which seem to place difficulties in the way of accepting this line of argument. As Mr. White has pointed out, a large proportion of the sediments in question is of limestone, containing quantities of corals and other fossils (E. A. Smith, *et al.*, pp. 226–31). It is not believed that the Alabama River can properly be held responsible for those deposits which are transported in solution and in a very finely divided state, and which may originally have come, in part at least, from far-distant rivers. Mr. White notes still another objection to this argument in the following words:

> The thickest and most important of the beds attributed to the Appalachian River, the Lignitic (900 feet), is composed of cross-bedded sands and clays, and

would seem, at first sight, more than all others, to have been deposited by this river; but a study of the whole area shows that this formation increases in thickness and coarseness toward the west, in western Alabama and in Mississippi; while east of the Alabama River it is very calcareous and inconspicuous, showing that these sandy sediments were brought down from the west instead of from the north (p. 36).

In view of the considerations stated above, it is not believed that any argument in favor of the supposed capture of the Appalachian River by a branch of the Sequatchie can be properly based on a comparison of the sediments opposite the mouth of the Alabama River with the amount of material eroded during Tertiary times from the basin of the Alabama or other rivers. So far as such evidence goes, there seems to be no reason for supposing that the Coosa-Alabama River was ever any larger than it is now.

Evidence from the character of the gorge below Chattanooga.—The third line of evidence developed by Hayes and Campbell in favor of the diversion of a southward-flowing Appalachian River by a branch of the Sequatchie River to the west, is based on the youthful character of the transverse gorge west of Chattanooga. They recognize the fact that the course of the river through a ridge capped by hard sandstone several hundred feet in thickness would necessitate, on the basis of either theory, a valley of younger expression at this point than east or west of it where the river follows weak rocks. Their argument is that the *degree* of youthfulness is too great to be accounted for on any other theory than that of a comparatively recent diversion of the river to that course by a process of stream-capture. This is a point which does not readily admit of demonstrable proof, and the best evidence is to be secured from a comparison with other valleys of known age and formed under similar conditions. Hayes and Campbell, therefore, compare the gorge of the Tennessee through Walden Ridge with a valley southwest of Scottsboro, Alabama, in the following words:

> While a direct comparison cannot be made between the Walden gorge and the upper Tennessee valley on account of difference in conditions, such a comparison can be made between the gorge and a valley in northern Alabama, extending from Scottsboro southwestward to the mouth of Flint River. . . . . It is nowhere less than six miles broad, and its floor is very regular, forming a portion of the Tertiary peneplain. The age of this valley is easily determined; it is carved in the Cretaceous peneplain; therefore it is more recent than the Cretaceous;

> it is continuous with the Tertiary peneplain, and hence was complete at the close of the Tertiary baseleveling period; and at the close of that period it was deserted by the stream which carved it. The conditions under which this valley was cut are practically the same as those now prevailing in the gorge through Walden plateau. In both cases the rocks are nearly horizontal, heavy sandstones capping the plateau, with easily erodible Carboniferous limestones beneath. Such conditions are highly favorable for rapid corrasion of a river channel. The sandstone cap is undermined, and its débris rolls down and forms a talus on the lower slopes. The rate at which the cliffs recede depends largely on the rate at which the sandstone talus is removed from the slopes and the limestone is exposed to erosion. No conditions could be more favorable for this rapid removal of the protecting débris than those now present in the Walden gorge, where the base of the slope is washed by a stream competent to remove all talus from the cliffs above, the coarsest as well as the finest. Certainly the conditions in the gorge are fully as favorable as they were in the valley west of Scottsboro when that was being cut, and the stream which flowed in that valley was probably smaller than the present Tennessee; therefore, if under the same conditions a smaller stream than the present Tennessee could cut so broad a valley as it did in northern Alabama during the Tertiary cycle, the conclusion seems inevitable that the present gorge through Walden plateau has been occupied a very much shorter time, and hence the Appalachian drainage was not diverted to its present westward course till after a part or the whole of the Tertiary cycle (pp. 113, 114).

While a comparison of the Tennessee gorge with some valley of known age may be expected to give us our best light on this particular phase of the question, two very serious criticisms must be urged against the comparison given above. In the first place, sufficient account is not taken of the details of geological structure in the two regions compared, although these details are features of prime importance in the present connection. In the second place, the comparison is one between the *Tertiary* valley southwest of Scottsboro and the *present* gorge of the Tennessee. The references are always to "the present gorge through Walden plateau," the conditions "now prevailing in the gorge," etc. A proper comparison can only be made between the Scottsboro Tertiary valley and the gorge of the Tennessee *as it also appeared at the close of the Tertiary period.*

When the geological formations in the region of the Scottsboro valley and in that of the Tennessee gorge are compared, it is found that the conditions under which the two valleys were carved were far from being the same. It is true that in each case we have soluble limestone capped by hard sandstone, but the sandstone cap in the two cases is of very different thickness. An examination of the Sewanee, Stevenson, and Gadsden folios of the United States Geological Survey shows that the sandstone covering thins out toward the Scottsboro region, this thinning being due in part to an original westward thinning of the beds, but more especially to the beveling of the successive formations by the Cretaceous peneplain, represented by the plateau tops. The Walden sandstone disappears entirely over much of the Sewanee area, northeast of the Scottsboro sheet, so that the underlying Lookout sandstone alone is represented on many of the plateau remnants; and while in the Stevenson and Gadsden regions the Walden sandstone covers a greater area, it is markedly thin, even on Sand Mountain, where the underlying Lookout sandstone comes to the surface over considerable areas, probably in part the result of a shallow synclinal fold. Over that part of the Stevenson region immediately northeast of Scottsboro, the Walden sandstone is wholly absent, and only a thin layer of the Lookout sandstone caps the plateau remnants. So, while we have no folio of the Scottsboro region itself, the conditions over the adjoining districts are such as to lead us to expect a much thinner cap of the sandstone over the lime about Scottsboro than in the vicinity of the Tennessee gorge. An examination in the field proves this to be the case. Just what the difference in thickness of the sandstone cap is in the two cases is difficult to determine with accuracy, owing to the fact that the limestone readily weathers out from under the overlying sandstone, allowing fragments of the latter to drop down and mantle the mountain slopes, thus concealing the limestone and making it harder to ascertain its true thickness. The tendency is to underestimate the thickness of the limestone, and correspondingly to overestimate that of the sandstone. But even if we assume the maximum possible thickness of sandstone over the Scottsboro region, and the minimum thickness over the region of the Tennessee gorge, there is still shown to be a markedly greater thickness at the latter place than at the former.

Ten miles southwest of Scottsboro the valley has its normal development, and the adjacent plateau remnants are well shown. Here, as elsewhere, the valley is seen to be cut largely in limestone, which shows conspicuously on the mountain slopes. Limestone float is abundant all along the foot of such slopes, and comparatively little sandstone is seen. Two sections in this vicinity showed the practically continuous limestone ledges up to within 190 feet of the top of the plateau or mountain. For reasons stated in the preceding paragraph, it is highly probable that the limestone continues still higher, no sandstone ledges being seen until nearer the top, and sandstone débris mantling the slopes for some distance. But even if we ascribe the entire thickness of 190 feet to the sandstone, the contrast with conditions at the Tennessee gorge is very marked. North of Scottsboro it appears that the sandstone cap was somewhat thicker, suggesting a progressive thinning toward the western end of the valley, although the possibility that the limestone goes higher up the slope than is apparent makes a definite statement impossible. Such a westward thinning would be in accord with the indications on the geologic folios of adjacent areas, however.

Turning now to the conditions at the winding gorge through Walden plateau, we find plenty of evidence that the gorge is cut largely in sandstone. Instead of conspicuous limestone ledges well up the mountain slopes, we find the slopes mantled with coarse sandstone débris, generally down to the level of the river. Only near the eastern and western mouths of the gorge was the limestone shown at all prominently, and this is where the gentle rise of the sides of the synclinal trough would naturally bring the limestone to a higher level; while in the Scottsboro valley the limestone is everywhere prominently shown well up toward the plateau summit. Limestone is shown at various other points throughout the gorge, but always, so far as seen, in limited exposures well down at the foot of the slope. Limestone float was little in evidence, usually only close to the small ledges referred to, sandstone débris being everywhere abundant. Although the limestone was undoubtedly greatly masked by the sandstone débris, exposures of the limestone on the spurs of the mountain, and the careful examination of float and ledges along the courses of side streams emptying into the gorge, indicated that in the main portion of the gorge the limestone-sandstone contact could not be far above the level of the river. In the half-dozen best sections seen, the limestone exposures or limestone débris always stopped short at elevations of between 100 and 200 feet above the river. The limitation of the limestone to the bottom of the gorge is also indicated by the presence of sandstone in ledges apparently in place well out on spurs projecting forward from the main base of the mountain. These spurs occupy a position which does not seem to admit of their sandstone being interpreted as débris that had been let down from above by the undermining of the limestone.

The geological map accompanying the Chattanooga folio represents a larger portion of the gorge as being in limestone. Thus the thickness of the limestone exposed in the gorge is shown as over 600 feet in places, and as less than 300 in others. Throughout a large part of the central portion of the gorge the 1,000-foot contour line is taken as the upper limit of the limestone, and the indicated thickness of between 300 and 400 feet of limestone may be taken as a fair average figure as given by this line of evidence. This leaves, as the map shows, a cap of between 600 and 700 feet of sandstone.

It appears, then, that if we take the more conservative estimates of the thickness of sandstone in the Walden gorge, the sandstone cap at that locality is still over three times as thick as the similar cap in the Scottsboro valley. If a thickness of sandstone be taken nearer that indicated by the sections given in a preceding paragraph, the contrast is still more marked. Such a difference in geological structure must result in a marked difference in form between the two valleys. The Scottsboro stream, having the thin cap of hard rock to cut through must have reached the underlying soft rock, and so have had ample opportunity to widen its valley under favorable conditions, while the stream through Walden gorge, having the thick cap of hard rock to contend with, still continued for a long time to carve a narrow gorge in the resistant beds. The great degree of contrast to be expected in this particular case will be more apparent after a consideration of the next point.

A second serious objection to the comparison between the valley southwest of Scottsboro and Walden gorge is found in the fact that it is throughout a comparison between the former as it was at the end of Tertiary times, and the latter as it is at present. As Hayes and Campbell have shown, the Scottsboro valley was completed at the end of the Tertiary period, and the valley floor forms a part of the

Tertiary peneplain. It has not been materially modified since, and therefore it is truly a Tertiary valley. On the other hand, while the Tennessee gorge had a certain form at the close of the Tertiary period, post-Tertiary cutting has lowered the gorge 250 feet, almost obliterating all traces of the old Tertiary valley floor at the higher level. Manifestly, then, the two valleys as they are at the present cannot be properly compared. The comparison becomes of value only if we conceive the post-Tertiary cutting in the gorge to be replaced, filling up the bottom of the gorge to the level of the Tertiary peneplain. We may then compare the two valleys as they were at the close of the long period of Tertiary baseleveling. Such a comparison shows a more marked contrast in geological conditions in the two valleys than that already indicated.

Hayes and Campbell have shown that the Tennessee River at Chattanooga has cut down its channel 250 feet below the level of the Tertiary peneplain, while the distribution of the Tertiary gravels, to be considered later, indicates that the gradient of the river through the gorge was then much the same as now. Hence filling up the gorge to that old level, and thus restoring the Tertiary peneplain, means a reduction of 250 feet in the extent to which the river had cut into the limestone then as compared with now. And since the vertical extent of limestone now shown in the gorge is between 300 and 400 feet, according to the larger estimates, this means that at the close of the Tertiary baseleveling period the Tennessee had cut into the limestone underlying the massive sandstone cap only between 50 and 150 feet; while if we accept the smaller estimates for the thickness of the limestone exposed at present throughout the main portion of the gorge, which seems to the writer to be nearer the actual conditions, we find that at the close of the Tertiary the river was in places still flowing wholly in sandstone, not having yet reached the underlying limestone. At this same time the stream southwest of Scottsboro had cut through the thin sandstone cap of that region and over 400 feet into the underlying limestone. The following figures illustrate graphically the different conditions obtaining in the two areas at the close of the Tertiary baseleveling period.

These diagrams are based on the more conservative figures given above. It is believed that the actual conditions at the close of the

Tertiary period would be more accurately represented by making the sandstone cap over the limestone of the Scottsboro valley (Fig. 4) thinner than it is shown, and the sandstone of the gorge (Fig. 5) enough thicker to show the gorge entirely in sandstone.

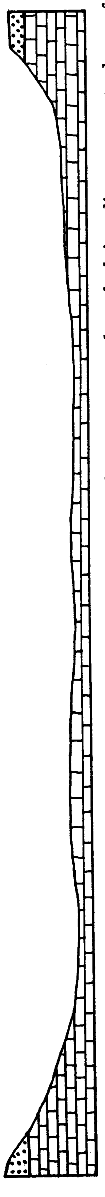

FIG. 4.—Section of Scottsboro valley showing relations of sandstone cap and underlying limestone at close of Tertiary cycle (same as at present). (Horizontal scale, 1 inch = 1 mile. Vertical scale, 1 inch = 2,000 feet.)

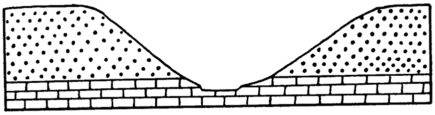

FIG. 5.—Section of Tennessee gorge showing relations of sandstone cap and underlying limestone at close of Tertiary cycle. (Scale, same as in Figure 4.)

But even on the basis of the more conservative representation, the contrast in conditions under which the two valleys were carved is such as to explain satisfactorily the difference in form which has been noted. Indeed, it is difficult to conceive how the gorge of the Tennessee could be otherwise than narrow and steep-sided as compared with the Scottsboro valley, since it was carved almost wholly, or possibly entirely, in hard sandstone throughout the long period of Tertiary baseleveling, and only during the comparatively very short post-Tertiary trenching have favorable valley-widening conditions existed; whereas the Scottsboro valley was carved largely in easily erodible limestone, favorable conditions certainly existing a vastly longer period in this case. It appears, then, that the gorge of the Tennessee might be more properly compared with other gorges cut through sandstone ridges since the Cretaceous period, such as those of the Delaware and Susquehanna Rivers through the Pennsylvania ridges; for while the present conditions at Walden gorge and the latter localities are different, they were much the same until comparatively recent times, barring the greater width of the Walden ridge, and a possible difference in hardness of the sandstone.

The degree of similarity between these gorges (Fig. 6) is what we should expect when the conditions under which they were carved were for so long a time so much alike; and inferences drawn from such a comparison seem more reliable than those from a comparison with a valley where the conditions were for so long a time so radically different. No comparison between the gorge through Walden Ridge, and the broad longitudinal valleys east and west of the ridge, can be made, since the latter were carved entirely on broad bands of soft rocks.

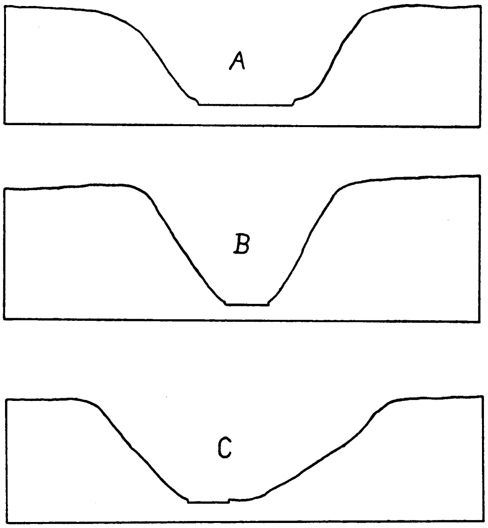

FIG. 6.—Profiles of (A) Susquehanna Watergap above Harrisburg through Second Mountain, (B) Delaware Watergap, and (C) Tennessee gorge. (Horizontal scale, 1 inch = 1 mile; vertical scale, 1 inch = 2,000 feet.)

It is believed, then, that when the geological conditions at the Walden gorge and the Scottsboro valley are carefully considered, and the comparison between the two made on the same time basis, the difference in form between the two will afford no evidence in favor of the recent diversion of the Tennessee River to a westward course. It is further believed that these considerations fully explain the present narrowness of the gorge on the basis of the alternative theory, the youthful features being just what we must expect under the conditions that have controlled erosion at this point since Cretaceous time.

Evidence from the distribution of the Unionidæ.—Six years after the publication of the paper by Hayes and Campbell giving the above lines of evidence, and the conclusions to which they led, Mr. Simpson reached the same conclusions from a study of the fresh-water mussels of the region. The facts that Mr. Simpson brought forth are as follows: *Pleurobema,* a genus of Unio, has its metropolis in the Tennessee River. It is not found throughout the other portions of the Mississippi basin. But it is found abundantly in the Coosa and Alabama Rivers. Also certain other forms of Unio common to the Mississippi-Tennessee basin are found in the Coosa-Alabama basin. From these facts Mr. Simpson concludes that at some time the upper Tennessee River must have flowed southward into the Coosa-Alabama River, since, to quote his words, "these forms cannot travel overland from river to river, but must have water communication in order to pass from one stream to another."

Mr. Simpson's argument in favor of the theory of capture is based on the assumption that the fresh-water mussels must have direct water communication (evidently meaning direct fresh-water communication) in order to pass from one stream to another. It appears that the recorded observations of many naturalists, and the facts of Unionidæ distribution, are both contrary to this assumption. In the first place, there are so many authentic cases where birds, insects, etc., have been taken with fresh-water shells attached to them, that students of the subject are compelled to believe in this method of dispersion of these forms from place to place. Darwin proved that young mollusks just hatching will attach themselves to the feet of a duck, and remain alive in this position out of water from twelve to twenty hours (p. 174). Mr. Arthur F. Gray, of Danversport, Mass., had in his possession the foot of a waterfowl to which was attached a bivalve shell. Canon Tristran shot a bird in the Sahara which had attached to it the eggs of some mollusk. Some shells attach themselves to plants which are carried away by birds (Darwin, p. 174). Insects are frequently taken with shells attached. There are at least five recorded cases of the capture of the water scorpion, *Nepa,* a large flying-bug, with small shells attached. The great water beetle, *Dytiscus,* is known similarly to aid in the dispersion of fresh-water Mollusca. The same is true of *Dineutes.* Mr. Albert P. Morse, of Wellesley, has kindly shown me specimens of these last two forms having attached shells. *Notonecta* has likewise been proved to carry these forms from place to place. Some of these insects are powerful flyers. Darwin records the capture of one of them out at sea, 45 miles from the nearest land (p. 174). Beddard, Kew, and other students of zoögeography regard birds and insects as undoubtedly important agents in the dispersion of fresh-water shells. Woodworth catalogues a number of agencies recorded as aiding in this dispersion, in addition to those mentioned above (pp. 214–17). It appears, then, that other means besides river-capture for the passing of fresh-water shells from one stream to another are not lacking. That these means are efficient is proved by the distribution of these shells. Ponds are sometimes made by excavating a place where no water stands ordinarily, lining the excavation with concrete and allowing the rain to fill it. These ponds, for a time devoid of life, gradually become populated with mollusks and other shells, proving, as Beddard says, the capacity for active or passive migration on the part of the Mollusca. Careful and successive observations have proved in some instances the actual time in which a given pond may become populated. R. Ellsworth Call records the presence of a western species of Unio in a small isolated eastern lake, which was located down between high hills, fed by a mountain brook, and absolutely foreign to any stream through which the species might have been introduced.

But the most conclusive objection to Mr. Simpson's argument in favor of the theory of capture is found in the actual distribution of the very shells upon which he bases his argument. Mr. Simpson finds the genus *Pleurobema* in both the Tennessee and Coosa-Alabama basins. He says that in no case are the species in the two basins identical, but only similar. The basis of the argument, then, is similarity of forms; but if mere similarity of form proves former river connection, certainly identity of form should prove it with double force. Accordingly, we should not expect to find the same species of *Pleurobema* in any two rivers of this section whose location is such as to render practically impossible a former connection with each other, either directly or by way of intervening streams. An examination of Mr. Simpson's later monograph on the pearly fresh-water mussels (pp. 745–65) is of value in this connection. As will be seen, he records *Pleurobema similans* Lea, from Black Warrior and Cahawba Rivers, Alabama; and Pine Barren Creek, Escambia County, Florida. So far as can be judged from available maps, previous fresh-water connection between the former and the latter is extremely improbable. *Pleurobema strodeana* Wright is recorded from Escambia

River, Florida, and Flint River, Georgia. Any former connection in this case seems improbable. *Pleurobema harperi* Wright is recorded from Altamaha and Flint Rivers, Georgia; and Suwanee River, Florida. Here, again, connection between either of the former and the later seems out of the question. Other cases might be added—indefinitely, if we continue with other genera than *Pleurobema.* If we find it impossible to hold river-capture responsible for the distribution of identical species in all these cases, then mere similarity of forms in the Tennessee and Coosa-Alabama basins cannot be regarded as a valid argument in favor of river-capture near Chattanooga.

If we carry this line of argument to its logical conclusion, the objections to it become even more apparent. Mr. Simpson records one group of Unios as occurring everywhere in the streams draining into the Atlantic from Labrador to Georgia (1900, p. 134). If the occurrence of the *Pleurobema* in the Tennessee and Coosa-Alabama Rivers proves river-capture in that case, then the distribution just referred to must prove a great succession of river-captures from Labrador to Georgia. Nor is this all. The same species is in one instance found in Europe, northern Asia, Japan, northern North America, and Iceland (p. 677). According to the argument advanced, this means an inconceivable series of river-captures. Such violent hypotheses compel the conclusion that some other means than river-capture is commonly operative in effecting the distribution of fresh-water shells.

Certain features of Unionidæ distribution have led some to believe that their dispersal may take place by migration along the seacoast from one river system to another, as well as by the means already considered. Mr. Simpson evidently regards this as a possibility in the case of another instance of supposed river-capture (1900, p. 135), but does not consider it in connection with the more important problem of the Tennessee, unless certain statements near the first of his article are meant to imply such a consideration indirectly. He states that none of the *Pleurobema* are found in the lower 300 miles of the Mississippi River, in the Pearl or Pascagoula Rivers, or any of the small rivers in Mississippi or Louisiana flowing into the Gulf (p. 134). If it is meant to imply by this that no migration down the Tennessee to the Gulf, thence along the coast and up the Alabama and other streams, could have taken place, because the intervening streams should, at the same time, have become populated by such a process, two answers may properly be made: (1) Such absence in the intervening streams is no more remarkable than that shown repeatedly in the distribution of the species of *Pleurobema* in the southern rivers, and of other forms elsewhere. (2) The migration along the coast may have taken place near the close of the Tertiary, at which time the rivers and portions of rivers referred to were not in existence. In this connection it is suggestive to note that, although Hayes and Campbell consider that the lower portion of the Tennessee River was diverted northward to the Ohio in recent time, not a trace of the Tennessee shells has been found to mark the supposed former southwestward course of the river through Mississippi.

The evidence recorded by Mr. Adams is much the same as that introduced by Mr. Simpson, except that Mr. Adams emphasizes more especially the *differences* existing between members of the same group found in the two river systems, and seeks to explain the differences by the proposed capture, whereas Mr. Simpson seeks to prove the capture by the similarity of these forms. It is believed that all of the phenomena noted are easily explicable independently of the theory of capture, and in this connection it is well to note that the presence of a longitudinal open valley across the low divide between the two basins is peculiarly favorable for the operation of some of the means of dispersal referred to above. The northward and southward migrations of birds along certain valleys are known, and where a low divide in a prominent valley alone separates the waters of two river systems it is to be expected that more or less mingling of forms will very likely take place.

In closing our consideration of this line of evidence, it is of interest to recall Mr. Simpson's statements regarding the dispersal of these shells, which appear in his paper on the *Distribution of North American Unionidæ*, published seven years prior to his Tennessee paper. In a footnote (p. 354) he observes:

> In many cases the Unionidæ seem to have had no difficulty in migrating across the country from river to river; an example of this being the Mississippi Valley species which now inhabit all the rivers of Texas, and some of those of eastern Mexico; while, on the other hand, species of South America extend up

> into Central America. The embryos, in some cases, may be carried by aquatic birds in the manner elsewhere mentioned in this paper; in others, they probably migrate across overflowed regions near the sea, in time of floods.

Farther on (p. 358), in accounting for the presence of *Unio luteolus* in both the Missouri and Columbia Rivers, Mr. Simpson says:

> I have traced it up the Missouri River to near its source, and when it is taken into consideration that the Marias, a tributary of this stream, heads within a few miles of Flathead Lake on Clarke's River, a branch of the Columbia, and that the embryos of Unios are provided with hooks by which they can attach themselves to the feet or feathers of aquatic birds, it is very easy to see how this species might have been carried from the waters of one drainage system to those of another.

Mr. Simpson does not consider the possibility of such means of dispersal when discussing the Tennessee problem, the whole force of his argument in that case lying in the statement: "These forms [the Unios] cannot travel overland from river to river, but must have water communication in order to pass from one stream to another."

It is believed, then, that the well-authenticated means of dispersal of Mollusca, and more especially the facts of Unionidæ distribution, are such as to render the argument in favor of the theory of capture, based on the evidence of the Unionidæ, invalid; for while it is believed that such a capture as has been proposed would result in the dispersal of the *Pleurobema* and other forms throughout the two basins, it is equally believed that other means of dispersal will account for all of the phenomena noted, some of which are inexplicable on the theory of capture alone.

SUMMARY OF EVIDENCE IN FAVOR OF THE THEORY OF CAPTURE

To review our consideration of the four lines of evidence in favor of the theory of a recent diversion of the Tennessee to its westward course through the gorge in Walden Ridge:

It has been shown that divides similar to that between the Tennessee and Coosa-Alabama basins exist in other regions at points where no large stream is ever supposed to have held its course. A consideration of the behavior of river-brought sediments under marine control, and of the character of the Tertiary sediments in Alabama, is believed to show the impossibility of properly basing any argument in favor of the capture on the comparison of sediments now exposed with amount of material eroded. A study of Walden gorge and the Scottsboro valley shows the invalidity of any argument in favor of the theory of capture based on a comparison of the two valleys, and satisfactorily explains the narrowness of the gorge on the basis of an alternative theory. The supposed evidence of the Unionidæ in favor of the theory of capture is seen to be based upon assumptions which do not seem to be warranted by due consideration of the various means of molluscan dispersal or by the facts of Unionidæ distribution. It is therefore believed that the arguments brought forward in support of the theory of capture are far from conclusive, and that the history of the Tennessee is still open to consideration. Certain lines of evidence, some of which have hitherto been unconsidered, appeal to the writer as weighing strongly against the theory of capture, and as strongly indicating the continued presence of the Tennessee River in its present path across Walden Ridge since Cretaceous time.

EVIDENCE IN FAVOR OF THE ALTERNATIVE THEORY

The evidence against the proposed theory of capture, and in favor of the long continuance of the Tennessee in its present course through Walden Ridge, is derived from a consideration of (1) the winding character of the gorge; (2) the character of stream-dissection on the ridge both north and south of the gorge; (3) the character of the divide between the Tennessee and Coosa-Alabama basins, south of Chattanooga; (4) the lack of sufficient inequality of levels between the valleys east and west of Walden Ridge; (5) the absence of the Tertiary river gravels from the supposed former southward course of the river.

Before considering these lines of evidence which appear to bear directly on the present problem, it is desirable to note one line of evidence which might be available in certain cases, and to make clear my reasons for not applying it in the present instance. When a mature stream has developed a broad, open valley, the floor of that valley will have a gentle slope downstream, represented by the line *AD* in Fig. 7. Now, if capture of this stream takes place at a point *B*, the portion of the stream *AB* will intrench itself, developing a profile *A′B′*. From the point of capture, *B*, the divide will be pushed in the direction of *D* to some point *C*, by what is termed the "inverted stream," whose profile is *B'C'*. It is possible that the profile *C'D'* may remain practically coincident with *CD*. In the interstream areas remnants of the old valley floor between *A* and *C* not yet destroyed by erosion will show surfaces which coincide with the prolongation of the line *CD* toward *A*.

On the other hand, if *C* represents a divide which has been long maintained, no large stream having flowed from *A* to *D*, then the profiles will be as represented in Fig. 8: streams flowing from *A* and *C* toward *B* to meet and find an exit from the valley developing the profiles *AB* and *BC*, while the stream flowing from *C* toward *D* developed the profile *CD*. Now, if the streams intrench themselves, remnants of the old valley floor in the interstream areas between *A* and *C* will show surfaces which do not coincide with the prolongation of the line *CD*. It may thus be possible, by a study of the interstream spaces, to determine whether the present profile of the streams, *A'B'C'D'*, which is much the same in either case, is developed as a result of capture (Fig. 7), or merely represents the intrenching of streams which have long maintained their present general relations (Fig. 8).

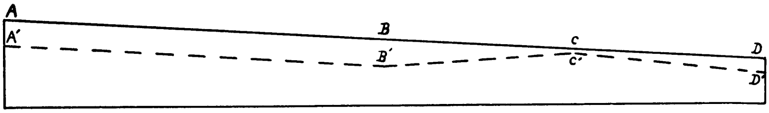

FIG. 7

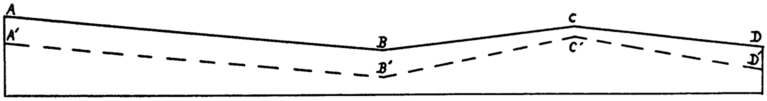

FIG. 8

The limited application of this test is evident. It would not apply to young streams with narrow valleys. It is equally obvious that if the streams had reduced their valleys nearly to baselevel, so that all slopes were very slight, and recent erosion had greatly dissected the former valley floors, the detection of the desired evidence might be impossible. In the case of the Tennessee drainage the streams had reduced their valley floors nearly to baselevel at the close of the

Tertiary cycle, and erosion subsequently to the uplift at the close of that cycle has been extensive. Sufficient time was not available for the work in the field necessary to prove whether or not this test was applicable, but it is not believed that satisfactory evidence of this nature is obtainable.

The winding character of the gorge.—In order to account for the winding character of the Tennessee gorge, those who support the theory of capture have been led to suppose a most complicated hypothetical series of drainage rearrangements. This series involves: the successive transference of divides from place to place along the headwaters of three or four separate streams, by a roundabout course some ten miles longer than that offered by the path of the stream supposed to be first encountered by the diverting stream; the removal of the massive sandstone cap throughout the courses of every one of those streams even to their headwater areas preparatory to the capture; and the definite localization of the axis of a broad, gentle uplift which is supposed to have determined the location of an assumed divide between the supposed contending streams. There are two difficulties in the way of accepting this explanation: It is impossible to accept the assumption that the several streams were able to breach the massive sandstone cap even to the divides between the streams, whereas much larger and more powerful neighboring streams, with all the advantage of post-Tertiary cutting, have scarcely begun to accomplish that work in their lower courses. This will appear more fully in a later paragraph. The proposed process of capture involves so much that is purely hypothetical that one is led to seek a less complicated explanation.

The winding character of the gorge is, on the other hand, what we should naturally expect if the meanders of the river are inherited from a former baseleveling period when the river meandered broadly over the site of the present ridge. Meanders which were developed when the river flowed with sluggish course over the Cretaceous peneplain would necessarily intrench themselves with some modification when the uplift occurred; and whatever the form of these meanders, no special and complicated explanation would then be necessary in order to account for each portion of the various curves. This more simple explanation finds confirmation in the succeeding lines of evidence.

Character of stream-dissection on Walden Ridge and Sand Mountain.—The streams occupying the open longitudinal valleys on either side of the ridge belong to that type known as subsequent streams, since they must have gained their present positions by a process of adjustment to weak structures from some former position more directly consequent upon the initial folding of the region. The branches of the subsequent streams which head up the ridge belong to the group of streams termed obsequent, since they have grown headward against the dip of the beds which they cut. It is one of the characteristics of obsequent streams that they are not located, so far as is known, by any specific structural factors, but develop at more or less regular intervals, as is required by the removal of rainfall. Over an area where practically uniform conditions prevail the development of such streams will be roughly uniform. We should not expect one stream of this class to dissect an area deeply, while similar adjacent streams had barely begun their work.

An examination of the Chattanooga and Stevenson topographic sheets shows that the dissection on Walden Ridge and Sand Mountain, north and south of the Tennessee gorge, has progressed at a fairly uniform rate. It also appears that the dissection is of no great extent, the integrity of the plateau remnant being quite well preserved in either direction. Only at the gorge is the flat-topped mountain cut wholly in two. Now, the theory of capture necessitates the assumption that one of the obsequent streams grew headward entirely through the mountain and cut down to the level of the main stream in the broad valley to the east, during the same time that its neighbors were able to make but a small beginning on the dissection of that mountain—an assumption which it seems difficult to accept. If one of the obsequent streams was able to cut its ways entirely through the ridge, then we should expect to find the ridge more or less nearly breached at various other points. This is distinctly not the case. The marked contrast between the amount of dissection at the gorge and elsewhere points to an entirely different origin for the gorge from that of breaching by an obsequent stream.

According to the suggested procedure of the supposed capture, the branch from the Sequatchie River to the west was aided in the breaching of the ridge by several small obsequents working back into the ridge from the valley to the east. Such a process seems to add to the difficulties of the case rather than to decrease them; the disposal of the rainfall of a given area on the ridge by several streams instead of by one must mean less powerful streams and decreased cutting in each individual case. That such streams should have been able completely to breach the thick sandstone cap of the ridge, even at their headwater areas, by the close of the Tertiary period, whereas their larger neighbors, with the additional advantage resulting from 250 feet of post-Tertiary incision of the main streams, have only begun that process in their lower courses, seems wholly incredible. (In this connection it must be borne in mind that such streams as flow short distances down steep slopes directly into the present Tennessee are not comparable with streams heading in the ridge, but flowing some distance out across the open valley to join the main stream, or its tributary, the Sequatchie. Thus, in the immediate vicinity of the gorge, where the streams enter the main Tennessee while it is still fairly within the limits of the Walden syncline, dissection of the ridge is very marked, as at points west of Brown's Ferry, east of Kelley's Ferry, and along Running Creek just south of the gorge. This local dissection, consequent in part upon the 250 feet of post-Tertiary trenching of the main Tennessee, is wholly in accord with the hypothesis that the Tennessee has held its present course since Cretaceous times.)

In order to account for the diversion of the upper Appalachian independently of this process, which involves such great dissection by obsequent streams, it has been suggested that the diversion may have been accomplished by what has been termed "cavern capture." This process involves a leakage from the Appalachian valley east of the ridge into the Sequatchie valley to the west, whereby a system of caverns was developed in the limestone below the massive sandstone cap of Walden Ridge, resulting in a diversion of the Appalachian River through this underground channel into the Sequatchie River, with the subsequent falling in of the cavern roof. There are several objections to this theory. It is difficult to conceive that the Sequatchie valley could have been lower than the valley of a great river to the east, as is pointed out more fully in a later paragraph, so as to admit of such a leakage as this theory involves. The process would entail a cavern or series of caverns twenty-five or thirty miles in length, having a beautiful meandering course, developed under a massive cap of hard rock which came down nearly or quite to the level of the valley floors. As Dr. Hayes has pointed out to me, such underground channels would in this case run counter to the trend of geological structures in the region, whereas it is generally true that caverns are developed parallel with such structures. The impossibility of accepting this theory is further evident from the consideration of points to follow. We are therefore forced to the conclusion that the present breach through Walden Ridge was made by the Tennessee itself, it having maintained its present course from a former baseleveling period.

Character of the divide south of Chattanooga.—The Tertiary peneplain on the present divide between the Coosa-Alabama and Tennessee basins, south of Chattanooga, is less than 1,000 feet above sea-level. Those elevations rising to or above the 1,000-foot contour are to be regarded as monadnocks which projected above the peneplain at the close of the Tertiary baseleveling period. Care was taken to verify this statement in the field, in order not only to guard against errors arising from incorrect maps, but particularly to eliminate the effect of possible warping of the peneplain so much as to bring it up to the 1,000-foot level. It was thus found that for a number of miles north and south of the divide those elevations contoured as 1,000 feet or over, as well as a number of elevations not so represented on the map, rose distinctly above the peneplain level, and that the above statement as to the altitude of the peneplain is correct.

Now, if we take the Ringgold topographic sheet and color the areas remaining unreduced at the close of the Tertiary cycle, it brings out very clearly one serious objection to the proposed theory of capture. It will be seen that numerous remnants, some of them over 200 feet in height and of considerable areal extent, were left unreduced on the present divide between the Tennessee and Coosa basins. The supposed former southward course of the Appalachian across this divide must have led between these remnants, because the capture is represented as taking place at the close of the Tertiary. In order to accept the theory of capture, then, we must conceive that a great river, flowing over soft, valley-making rocks, still found itself at the close of the long period of Tertiary baseleveling, confined for a number of miles in one part of its course (the present divide) by soft rock monadnocks of considerable magnitude to a valley less than two miles in width. This, however, is inconsistent with the accepted theories of valley development. It is thus seen that the features of this present divide are not such as would characterize a region of soft rocks occupied for a long time by the middle course of a great river. On the contrary, the frequent occurrence and large size of the unreduced remnants contrast strongly with the portions of the present Tennessee valley in the same rocks north and south of the gorge, but compare favorably with other divides between the headwaters of small streams, as, for example, that between East Chicamauga and east Armuchee Creeks, on the opposite side of Taylor Ridge, where no large stream is supposed to have ever held its course. When seen in the field, this objection to the supposed former southward course of the Tennessee across this divide is brought out even more strikingly than on the maps; and one is forced to conclude that the river has held its present course for a much greater period of time than since the Tertiary, and that no great Appalachian River could have flowed southward across this divide.

It is possible that an appreciation of this difficulty led Dr. Hayes to place the date of the diversion later than was done in the earlier paper by himself and Mr. Campbell. In the original essay the statement was made: "That the Appalachian drainage was diverted to its present course before this uplift is quite certain, for no channels are cut in the Tertiary peneplain across the Coosa-Tennessee divide" (1894, p. 115). In the later paper Dr. Hayes says:

> The large axial stream in the Appalachian valley continued to flow southward across the present divide for a short time after the uplift, but it was able to cut its channel less than 100 feet in the peneplain before it was diverted to a westward course (1899, p. 55).

It will be seen that this latter interpretation, which regards the present level of the divide as a channel cut below the peneplain instead of a part of the peneplain itself, would mean a reduction of something less than 100 feet in the heights of the monadnocks referred to, and a decrease in their areal extent. But while this provides for a somewhat wider valley for the supposed Appalachian River, it does not fully satisfy the objection urged, and does involve two other serious difficulties. If we accept a theory of a channel across this divide at the point north of Lafayette, we must account for the fact that small branch streams all over this area have been able to develop low, flat divides of remarkably uniform altitude, and having the same elevation as the channel in question. And, since in nearby areas elevations of 1,000 feet are represented by Dr. Hayes as monadnocks rising above the peneplain, we must either accept the idea of the narrow valley north of Lafayette referred to in the preceding paragraph, or else assume a very restricted local warping of more than 100 feet in four miles. It is also true that no direct evidence of the existence of any channel across the divide has been presented. For these and other reasons that will appear, I am forced to agree with the earlier statement that "no channels are cut in the Tertiary peneplain across the Coosa-Tennessee divide."

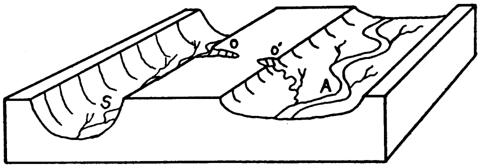

Fig. 9

Insufficient inequality of levels between the two valleys.—In order that one stream, S (Fig. 9), may divert another stream, A, from its course, it is essential that the stream S occupy a level so much lower than its neighbor A that even the uppermost headwater portions of the branch O which effects the capture shall eventually be able to work at a lower level than that of the stream to be captured. That a small branch of the Sequatchie River, a stream which is itself comparatively small, could work back through a high mountain barrier along a course over 40 miles in length, and still have its headwaters low enough to capture the large Appalachian River, demands that the Sequatchie valley west of the ridge should have been much lower than the Appalachian valley to the east. Several conditions indicate that such a marked inequality of level did not exist between the two valleys at the close of the Tertiary cycle.

On theoretical grounds alone we should be led seriously to question the possibility of such an advantage of position developing under the conditions preceding the supposed capture. It is difficult to conceive that a small stream like the Sequatchie, having its very beginning less than 70 miles to the northward, and flowing over 300 miles to the sea without receiving the waters of any large stream, could have reduced its upper course to a lower level than the middle course of a neighboring great Appalachian river. It is true that the smaller stream would have had some advantage of more direct outlet to the sea, as the region of the gorge is something over 300 miles from the mouth of the Sequatchie and about 400 miles from the mouth of the Appalachian, as represented on Hayes and Campbell's map of the Tertiary peneplain. It is also possible that there is some difference in the character of the rocks over which the streams were flowing, which was to the advantage of the smaller stream, although both were developed largely on soft rocks. But, after making all due allowance for these advantages, it is still impossible to admit that, whereas the great Appalachian River still had a fall of 3 inches per mile throughout its middle and lower courses, the comparatively small Sequatchie had reduced its gradient almost to zero even in its upper portion, as has been represented.

The fact that the Tertiary peneplain is somewhat lower in the Sequatchie valley than in the valley east of the ridge, while presenting grave difficulties in the way of a satisfactory explanation on the basis of the theory of capture, is wholly in accord with the alternative theory. We should expect the peneplain to be higher on the eastern side of the ridge, for two reasons: it is there farther upstream; and, what is probably of greater importance at this point, the stream in flowing from east to west passes through a mountain barrier which sheds abundant waste into its waters and obstructs its passage with coarse débris, compelling the maintenance of a steeper gradient throughout 25 miles or more; and when it is remembered that nearly or quite to the close of the Tertiary period the mountain served as a sandstone barrier in the path of the stream, it is seen that the baseleveling process must necessarily have gone on at a higher level in the valley in soft rocks east of the ridge. The observed difference in elevation is not greater than we should expect under the conditions referred to, and is not believed to be sufficiently great to account for the proposed capture, even were it possible for this difference to have been developed under the conditions imposed by the theory of capture.

Hayes and Campbell report the occurrence of the Tertiary river gravels on remnants of the Tertiary peneplain about Chattanooga, 250 feet above the present river, and in the Sequatchie valley, 150 feet above the river. If this difference of 100 feet in the relative elevation of the gravels were correct, it might be advanced as evidence in favor of the theory of capture; for on the basis of the alternative theory we should expect to find the gravels about as high above the river on one side of the ridge as on the other. On the contrary, if these gravels should be found 250 feet above the river in the Sequatchie valley, that in itself would be practically conclusive against the proposed capture, as it would show the former presence of the river at an elevation incompatible with the theory advanced.

North of Shellmound, in the Sequatchie valley, is a series of hills which rise well above the present valley floor. The contour lines show the summits of these hills to be something over 200 feet above the river. The Tertiary gravels, of material that could have been brought from far to the northeast by the Tennessee River alone, are abundantly developed on these hills, completely cloaking the summit in one case. Barometric readings showed that the gravels occur up to 265 feet above the level of the river itself, or about 230 feet above the river floodplain.

Absence of Tertiary gravels south of Chattanooga.—The Tertiary river gravels are abundantly represented about Chattanooga and in that portion of the longitudinal valley to the northward of the city. These gravels occur capping remnants of the Tertiary peneplain and widely distributed over lower levels. Their presence in the valley west of the ridge and southward from the gorge has been also noted. Therefore, if the river flowed southward into the Coosa-Alabama system until the close of the Tertiary cycle, we should find ample evidence of that fact in the distribution along this former southward course of the gravels which are so abundant along the present course of the river. These gravels cannot be confused with any that might be derived from sandstones or conglomerates locally represented, but, as has been pointed out by Hayes and Campbell, must have been brought from far to the eastward. And since these gravels are so well preserved on the small remnants of the Tertiary peneplain situated near the present river and subjected to extreme erosion, they should show doubly well on the beautifully preserved portions of the peneplain near the present divide south of Chattanooga where post-Tertiary erosion has been at a minimum. On the other hand, if the Tennessee River took its present westward course before the close of the Cretaceous period, and has maintained that course throughout all Tertiary and more recent time, we should not expect to find any such development of the gravels in the valley southward from Chattanooga. Indeed, even if in earlier Cretaceous times the river may have held some course carrying it farther southward in this region (as is possible, perhaps even probable, on the basis of either theory), the most that we could expect to find in the way of gravels would be occasional scattered pebbles having no relation to the Tertiary peneplain, since the erosion of Tertiary time must have swept away all but occasional traces of what may have existed in a former period.

North and south of the divide the valley was examined for a distance of forty miles to ascertain the character of the stream dissection and to discover traces of the Tertiary gravels. About 100 miles of road were traversed, peneplain remnants being visited and beds of streams examined. In all this district not more than a few dozen pebbles were noted, aside from the angular fragments of chert, etc., evidently of local origin. These gravels occurred at scattered intervals, usually only a few at a place, and in or near the beds of streams draining high land areas. A longer and more detailed search would, of course, show other scattered traces of these gravels, but their extreme scarcity cannot be doubted. This remarkable lack of the gravel seems irreconcilable with the theory of capture, but is just what we should expect on the basis of the alternative theory.

On the divide between the Tennessee and Coosa-Alabama basins the Tertiary peneplain developed in this broad valley east of the ridge is very well preserved. As has been pointed out before, this peneplain is not well developed across the entire breadth of the valley, but where it has been so developed it remains very little dissected by subsequent erosion. The conditions are here especially favorable for the preservation of the gravels represented elsewhere so abundantly on mere scattered remnants of the peneplain. But not a trace of the gravels could be found over this area, nor on any surface elsewhere south of Chattanooga which could be referred to the Tertiary peneplain. It thus appears that the true Tertiary gravels are wholly absent in the valley southward from Chattanooga—a fact which forces us to the conclusion that this valley was not occupied by the stream which left such abundant evidence of its presence on the Tertiary peneplain elsewhere.

SUMMARY AND CONCLUSIONS

There are many features in the physiography of the Chattanooga district which are of great interest and importance, to which it was impossible to give special attention in the time at the writer's disposal. A detailed discussion of these features will be found in the reports by Dr. Hayes and Mr. Campbell. It may be said in general, however, that it appears that all of these features may be interpreted in accordance with the theory that the Tennessee River has held its present course since near the close of the Cretaceous period. The warping of the peneplains, which was supposed to determine the point of the proposed capture, may doubtless be present; and while it is not believed that such a broad, gentle arching as marks that region could sharply limit a series of divides to a given line representing the axis of the uplift, the presence of such warping is perfectly admissible on the basis of the conditions which are believed to have existed. That the drainage on Walden Ridge north of the gorge is to the eastward, while the drainage south of the gorge is to the westward, seems wholly in accord with what we should expect when the master-stream of the region is east of the ridge in the one case, and west of the ridge in the other. Those streams flowing into the master-stream by the most direct route would have a marked advantage over their neighbors flowing in a longer, more roundabout course, and would in consequence gain control of a large part of the area drained, pushing the divide to the western part of the ridge north of the gorge, and to the eastern part of the ridge south of the gorge. That the drainage in Cretaceous times may have been very different in places from what it is now, and that parts of this drainage may have persisted far enough into the beginning of the Tertiary cycle to leave traces of its existence on portions of Walden Ridge, is conceivable on the basis of either theory.

In summing up the evidence which has been presented in favor of the theory of a recent westward diversion of the Tennessee from a former southward course, it has been pointed out that while the facts noted in that connection admit of a rational interpretation on the basis of the theory of capture, they are to be explained just as readily and satisfactorily entirely independent of that theory.

On the other hand, there are certain grave objections to the proposed theory of capture, and certain lines of evidence which seem to prove that the Tennessee River has held its present course throughout Tertiary and more recent times. The winding character of the gorge, on the basis of the theory of capture, necessitates a process of diversion so involved and complicated that one is led to seek a more simple explanation for the phenomenon. The conception of meanders inherited from a former baseleveling period offers such an explanation. The character of stream-dissection on the ridge both north and south of the gorge is seen to bear strong evidence against the theory of capture, but is wholly in accord with the alternative theory. The complete breaching of the massive sandstone cap in several places by small streams at a time when larger and more powerful streams had scarcely begun that work, appears incredible. The divide south of Chattanooga is seen to present features distinctly different from what we should expect had a large stream flowed across it until the close of the Tertiary baseleveling period, but well in accord with the features observed on other divides developed by small streams working under similar geological conditions. In order to accept the theory of capture, we must admit that the headwater portion of a comparatively small stream, having, apparently, no marked advantage in regard to its length or the rocks over which it flowed, was able to reduce its valley to a considerably lower level than the middle portion of a great river near by—a thing which does not seem possible. The supposed former difference in relative elevation of the river-brought gravels above the Tennessee in the two valleys—advanced in favor of the capture—is seen not to exist. The altitude of these gravels noted in the Sequatchie valley strongly negatives the possibility of the proposed capture. The absence of the gravels from the peneplain southward from Chattanooga and the presence of nothing more than occasional scattered pebbles whose distribution indicates their Cretaceous age, completes the evidence that the Tennessee River has persisted in its present course through Walden Ridge for a long period of time, probably since the close of the Cretaceous period at least.

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